Variance of Ultralightweight Space Telescope Technology Development Priorities with Increasing Total Aperture Goals

by
Edward E. Montgomery, Program Development, Marshall Space Flight Center

Abstract

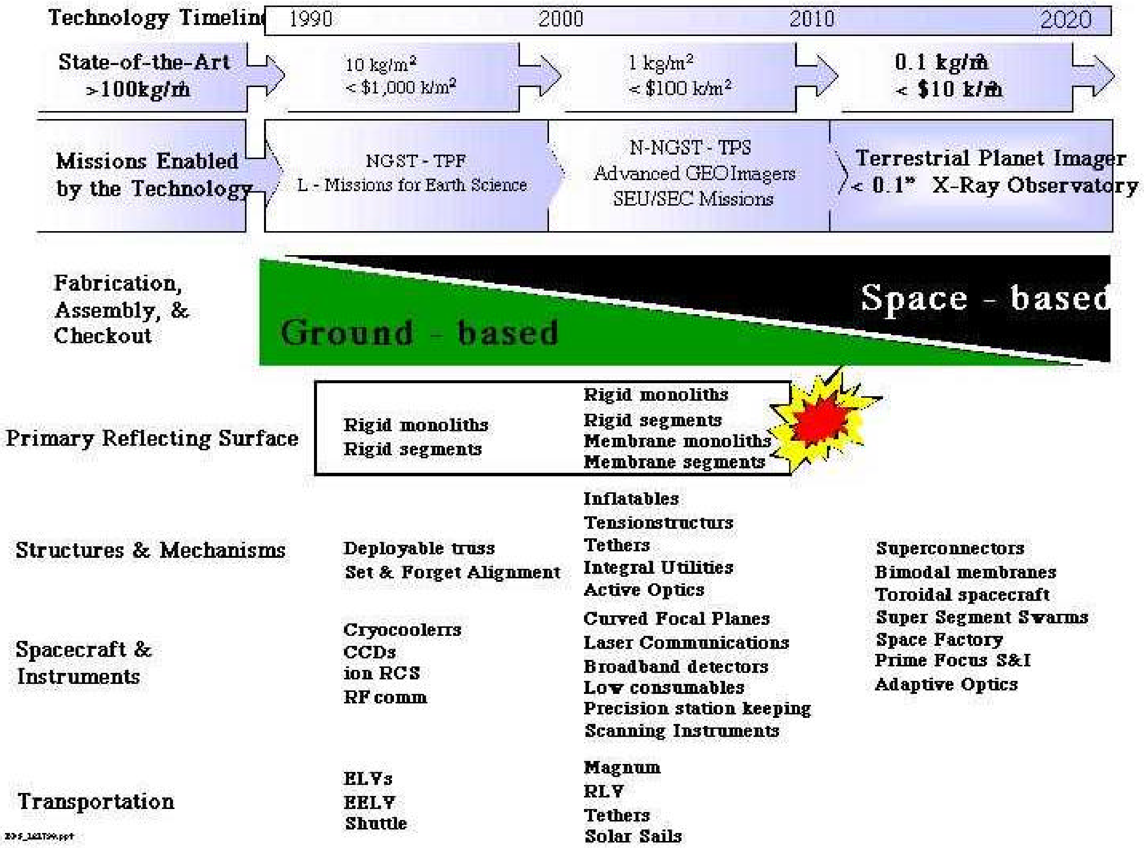
An analysis of several past concept development efforts for visible/IR large aperture space telescopes leads to the development of mass versus aperture scaling laws for rigid segmented and thin membrane primary mirror telescopes working in conjunction with active correction optics. A parametric study using the scaling laws reveals that for smaller apertures, there is more benefit to be gained from developing ancillary hardware than in reducing the basic mirror areal mass. For larger telescopes the converse is true. This study seeks to identify at what aperture size the transition occurs and what natural technology development paths exist.

Background

Technology needs will be similar, but their relative priorities are expected to be different for a two-meter space telescope than an eight-meter telescope. Similarly, it is also expected that space telescopes 20-40 meters in aperture will involve a different program of retiring high risk technologies than observatories with 8-10 meter apertures. Ultimately, apertures with kilometer size collectors drive another identification of the premium characteristics in its component technologies. NASA attempts to plan technology roadmaps to meet both criteria: (1) providing timely availability in support of near term missions as well as (2) making progress on as straight a path as possible toward enabling the further out missions. Some of the penalties of not doing this effectively are:

- expensive slips in near term mission launch dates,
- inefficient “wandering” through the development of dead-end technologies, and
- disruption in the NASA mission due to inadequate new opportunities enabled by new technologies.

While the advent of revolutionary new technologies can be expected, their specific form and impact cannot. Nevertheless, examining the near parameter space of space telescope systems design to learn some principles that can be used to guide technology selection is still worthwhile. It also is helped by the simple, but important observation that resolution and sensitivity of scientific observations varies fundamentally with aperture size. As a result, NASA program planning (see figure 1) logically shows a progressive growth in space telescope dimensions. While this argument over-simplifies the wavelength, operating temperature, observatory location and sparse-versus-filled aperture issues those subtrades all indicate a benefit from increasing aperture, which can offset, but not reverse the fundamental principle of growth in aperture.



Technology Timeline
1990
2000
2010
2020
State-of-the-Art
>100kg/m²
10 kg/m²
< $1,000 k/m²
1 kg/m²
< $100 k/m²
0.1 kg/m²
< $10 k/m²
Missions Enabled by the Technology
NGST - TPF
L - Missions for Earth Science
N-NGST - TPS
Advanced GEO Imagers
SEU/SEC Missions
Terrestrial Planet Imager
< 0.1" X-Ray Observatory
Fabrication, Assembly, & Checkout
Ground - based
Space - based
Primary Reflecting Surface
Rigid monoliths
Rigid segments
Rigid monoliths
Rigid segments
Membrane monoliths
Membrane segments
Structures & Mechanisms
Deployable truss
Set & Forget Alignment
Inflatables
Tensionstructurs
Tethers
Integral Utilities
Active Optics
Superconnectors
Bimodal membranes
Toroidal spacecraft
Super Segment Swarms
Space Factory
Prime Focus S&I
Adaptive Optics
Spacecraft & Instruments
Cryocoolerrs
CCDs
ion RCS
RF comm
Curved Focal Planes
Laser Communications
Broadband detectors
Low consumables
Precision station keeping
Scanning Instruments
Transportation
ELVs
EELV
Shuttle
Magnum
RLV
Tethers
Solar Sails

Figure 1. Vision of Technology Trends in Future NASA Space Telescope Missions

This study will begin the process by considering the major contributors to space telescope masses. Then a parametric model of space telescope mass which estimates the variation of those major contributors as a function of increasing aperture size has been built and is described. Then it will consider the restricitons imposed by packaging those systems for delivery to the orbital destinations.

Relative Importance of Space Telescope Component Masses

Figure 2 illustrates the results of a study done by George Sevaston of JPL a few years ago that began with the Large Deployable Reflector (LDR) top level mass estimate summary. Then he postulated how it might be changed with infusion of some newer technologies that have arrived on the scene since that study was performed. He also included a step that recalibrated the estimate for the more difficult precision required for diffraction limited operation with a 500nm wavelength instead of the LDR baseline, 30 microns. If the goals stated in figure 1 are for visible/IR large space telescope systems, the options shown will not be acceptable. LDR weighed in at around 68 kg/m2 and the best modification case, the membrane option, still required 20 kg/m2. If you don't count spacecraft and science instrument mass, consumable, or the sunshade, those numbers don't improve much because it is assumed a fairly massive corrective secondary is needed. If you can neglect the correcting system, then the areal densities begin to approach the 0.5-25 kg/m2 goals being suggested for the near to mid term.

Telescope Architecture Comparison

	LDR[1]	Updated LDR[2]	PAMELA Primary[3]	Membrane
Aperture (m)	20	20	20	20
Primary Reflector Surface Error (microns rms)	3	30	0.025	30
Minimum Diffraction Limited Wavelength (microns)	30	0.5	0.5	0.5
Mass (kg)				
Primary Reflector	4,710	3,000	7,800	150
Sunshade	2,432	400	400	375
Active Optics Assembly	2,045	5,000	0	5,000
Science Instruments	3,372	150	150	150
Spacecraft	6,133	2,000	2,500	400
Consumables	2,629	1,000	500	200
Total Mass	21,321	11,550	11,350	6,275

1 Cryogenically cooled science instruments

2 5 kg/(m^2) panels, no primary actuators, inflatable sunshade

3 25 kg/(m^2) primary

Note: HST is estimated to have a mass of 10,000 kg. Its aperture is 2.5 m and its minimum operating wavelength is 0.2 microns.

Figure 1. Comparison of Telescope architectures, after Sevaston [1]

Modelling information was also drawn on a more detailed study done at MSFC for the ULTIMA program in the spring of 1995. Figure 3 shows a comparison of a twenty-meter visible/IR cryogenic space telescope mission that was very similar in many rspects to the current concept for the Next Generation Space Telescope (NGST). Although it was generally a less optimistic estimate (nearly three times the mass of the previous example), the study did address each subsystem separately in a ground up concept development effort. Primary mirror only areal densities were 0.4 kg/m2 for the membrane case (see figure 4) and around 40 kg/m2 for rigid segments. These numbers also fit the near and mid term goals of figure 1 fairly well.

An analysis of the data in figures 2 and 3 along with discussions with the trade study experts behind the ULTIMA design provided a number of useful design rules. The science instrument mass of 1310 kg was reasonable and does not change in the trade-off between rigid and membrane primary mirrors. The Primary Mirror Support Structure should be equivalent to

70% of the mass it serves (the primary mirror). The metering truss between the primary mirror support structure and the secondary mirror should be ten times the mass it serves (the secondary mirror). For an Earth-Sun Libration point orbit, the attitude control system should be five percent of the mass it serves (the total spacecraft mass). The electrical power system (EPS) mass should be equivalent to the Science Instrument mass. The thermal control system (TCS) mass should be equivalent to 80% of the EPS mass. The remaining spacecraft and structural connections should be equivalent to 45% of the mass it serves (EPS, TCS, ACS, SI).

Large Aperture Space Telescope
Telescope Mass (ROM)

	Segmented Primary (kg)	Membrane Primary
Primary Mirror (20m)	9420	100
Secondary Mirror (2.4m)	181	181
SI Complement	1310	1310
PM Support Structure	6594	500
Metering Structure	2117	2117
Light Shade	2734	700
SI/Subsystem Module Structure	2608	2608
Electrical Power System	1500	1500
Comm & Data Handling	200	200
Attitude Determination & Control	1600	1600
Thermal Control System	1200	1200
Misc. (5%)	1473	601
Subtotal	30937	12617
Contingency (30%)	9281	3785
Total Mass	40218	16402

Figure 3. Comparison of Mass estimates for ULTIMA 20-meter design baselines [2]

To support trade studies focused in that particular area, a more detailed model of the command & data-handling model were developed. That model is described in Reference 1 and not discussed here further to maintain brevity. Essentially, it calculates wiring and processor masses for different primary mirror configurations.

Finally, basic scaling laws were derived form the recent Inflatable Antenna Experiment (IAE). Summary design data was used to specify membrane and supporting torus thickness and diameters. A common torus design model was developed. Aluminum-coated polyimide was assumed as the basic membrane material. For the inflation-formed case a very thin (5-micron) cover faceplate was assumed to cover primary made of a one-mil polyimide sheet coated with 1000 angstroms of aluminum. For the electrostatic case,

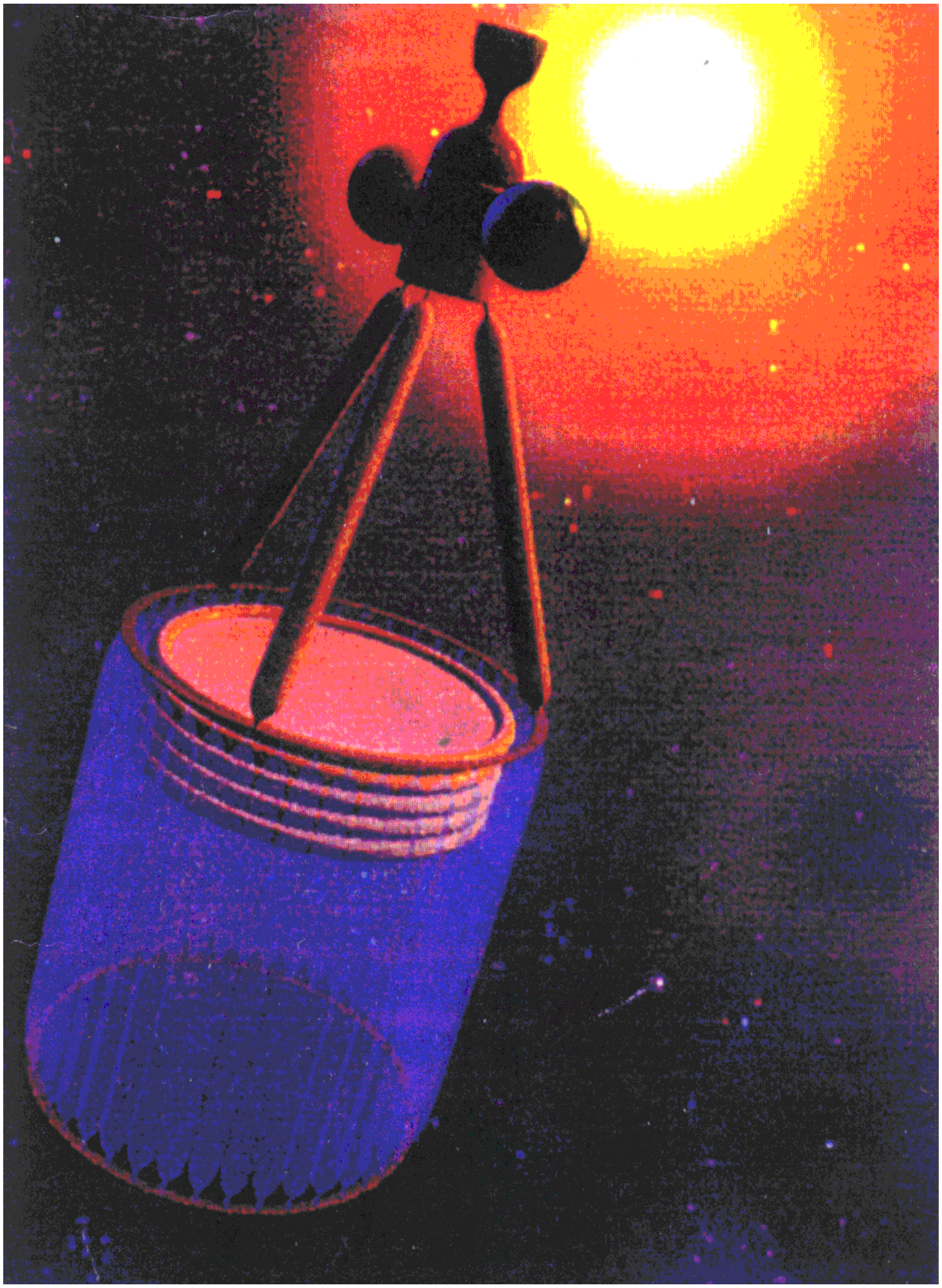


Figure 4. Artists concept of a 20 meter space telescope with integral solar thermal propulsion using ultralightweight membranes for the primary mirror/solar collector

it was assumed that five layers of coated membranes would be needed because studies had shown that the fast mirror curvatures need by typical large space observatories required far too much electrical field and power. Therefore, the total deep curvature was assumed to be achieved stepwise in layers of ever-increasing curvature.

The design rules derived were:

- Torus diameter is 3% of total aperture

- 1000angstroms of aluminum represents a good estimate of reflective and electrostatic coatings

- 10kv power supplies + cabling should be assumed for each of 216 subapertures in the electrostaticly charged case

- Inflation gas is negligible mass

<u>Study Cases</u>

There are currently several classes of technology reasonable to consider for future large UV/IR space telescope primary mirrors. Rigid reflectors may be minimally segmented and make use of an auxiliary optic to correct wavefront distortions. It may be finely segmented to control distortion at the primary and hopefully eliminate the need for a downstream corrector optic. Alternately the primary may be composed of a flexible, very thin membrane that is rigidized after deployment by some agent (gas inflation, electrostatics, epoxies, etc.). Most concepts tend to employ a single membrane across the full aperture. While segmented membranes are possible, they are problematic because there is usually a considerable size region of unusual area on the perimeter of the membrane and because complex curvatures can be difficult to achieve and hold.

The finely segmented primary reflector is identified here as having hexagonal rigid segments whose diameter is on the same order of the finest spatial scale to be corrected in the optical train of the telescope (assuming no external distortions as with adaptive optics in an atmosphere). A second is composed of larger rigid segments. An additional corrector optic located elsewhere in the optical train may or may not be appropriate for these type systems. The third type is the full membrane primary reflector that also may or may not require a corrective optical system, but must always have an external system for imposing shape control to some level on the flexible membrane. The last case is the diffractive optic. These are not usually considered viable because of the large mass of material needed to bend light enough to concentrate it sufficiently for most large space observatory concepts. Besides being massive, it will tend to be lossy as well. An alternate is the flat fresnel zone plate, which is much easier to manufacture and deploy, but also tends to be lossy. Some advantages and disadvantages of the options are listed in figure 5 in comparison to a monolithic, solid shell primary mirror. The latter would be simplest and therefore potentially easiest to deploy, require no power, and could be made with fast, even aspheric curvature using techniques better known than those to produce an alternative technology. But launching such a large area would be nearly impossible and the manufacturing to make a blank and figure it on orbit would likely be imposing, too. NGST has currently gone the second path towards segments manufactured as large as possible. Currently their size is limited by available manufacturing facilities and available launcher payload shroud diameter. A potential disadvantage is that such segments are not useful to ground observatories and don't achieve any economical growth capability. Smaller segments would require some production engineering, but once in place could continue to amortize costs over many missions on the ground and in space. Thin films (membranes) are significantly lower in weight, but good optical performance remains elusive. Although facilities for spin casting 10-meter flat films are in existence, larger.

Type Construction	Advantages	Disadvantages
SOLID SHELL	Simplest Easiest to deploy No power required Fast Curvature	Inefficent Packaging for launch Not adaptive
LARGE SEGMENTS	Efficient Packaging for launch Adaptive Fast Curvature	Limited spin-off value
SMALL SEGMENTS	Efficient Packaging for launch Adaptive- very fine scale High spin-off value Fast Curvature	Requires Production Engineer'g
THIN FILM	Lowest Weight	Poor Optical Figure Quality Requires elesctrostatic control Packaging difficult Large dia. fab. difficult Slowest Curvature
THIN FILM SEGMENTS	Low Weight Fabrication easier Efficient Packaging for launch	Segment shape a problem Requires electrostatic control Adaptive control difficult Slow Curvature

Figure 5. Basic Advantages and Disadvantages of Ultralightweight Mirror Construction Options

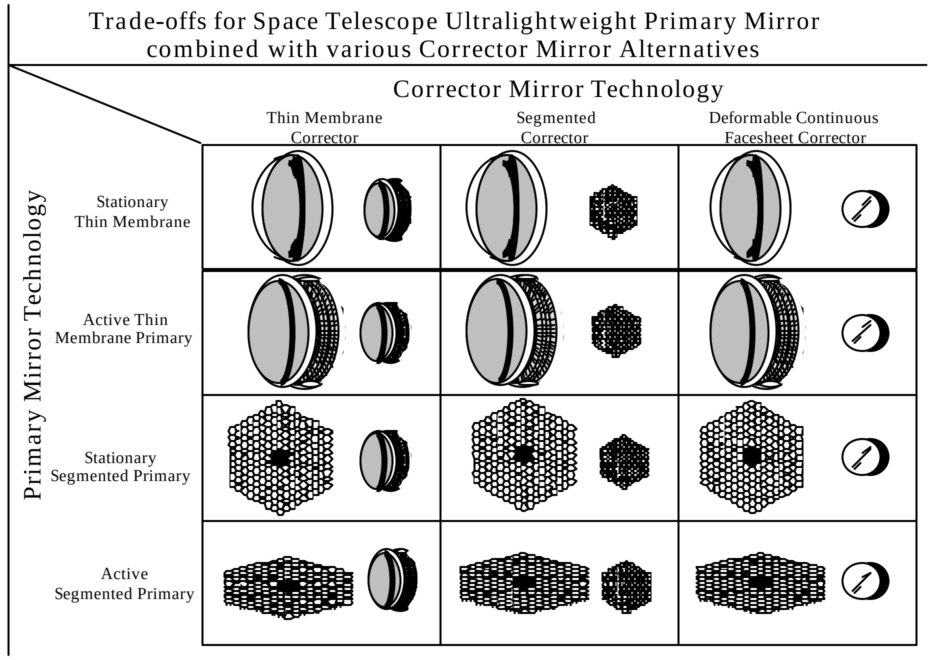


Figure 6.

sizes will be difficult. That suggests the last row, where the primary would be made up of thin film segments. Unfortunately, most designs for thin film reflectors have peripheral dead zones that would make the combined optical performance of a closely packed array difficult to achieve

The trade space for this study looks at the permutations of a primary mirror and secondary mirror pair, each potentially a rigid mirror or a thin film membrane, and each stationary or actively shaped for wavefront control. Figure 6 depicts those options.

Parametric Model

A trade study was performed on a simple cassegrain primary with the central segment and the next ring of segments removed. To minimize both the total number of segments and the size of the central obscuration of a 20-meter hexagonal aperture, 8 rings of segments were chosen. This leaves a central obscuration of only 5.9% of the total aperture. It requires only 210 segments each having a 1.18-meter diameter flat-to-flat (ftf). A formula derived to fit historical data that varies areal density of rigid segments as a function of segment diameter was derived.

δ = areal density [kg/m2] = 9.7 + 17.8 d   where d = hexagonal segment diameter(ftf) [m]

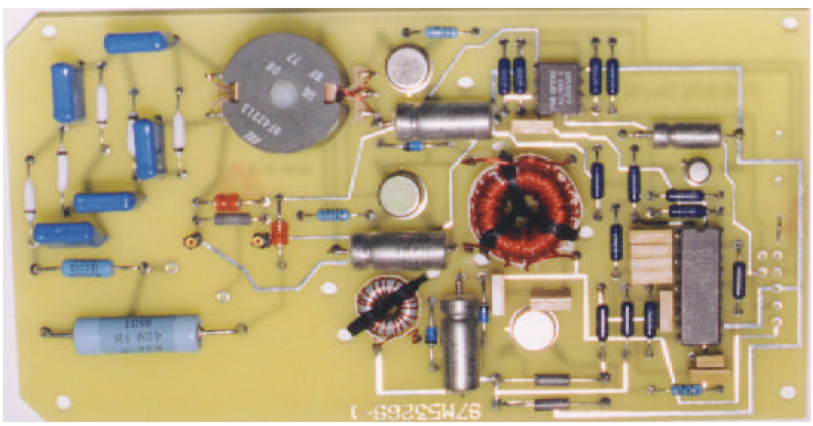
It models a lightweight technology level consistent with 25 kg/m2 for 1 meter class optics and therefore is pessimistic by current planning standards. For membrane mirrors, the calculations were conservatively based on material densities of 1.4 kg/m3. The inflation-deployed case is shown in figure 4. The electrostatic case assumed a five-layer construction of 1 mil (.00254 cm) thick CP membranes.

An analysis of the power requirements for activating segments (electrostatically or on conventional actuators) identified the key drivers of EPS being the cabling and the power management and distribution boxes. The size of these components were determined by peak power load which is determined fundamentally by the mass being moved by the actuators and the control bandwidth. Peak power (Pp) is then:

$Pp = (m\,\omega^3 a^2)/2$, where m = subaperture mass[kg],
ω = control bandwith[hz], and
a = actuator stroke length[m]

Most modern space observatory concepts are assuming set-and-forget type actuators; but even if it were operated at a continuous bandwidth as high as a few hundred hertz and the total actuator stroke were as much as 10 microns, the peak power requirement is still less than a watt per segment. Even if all 210 segments were simultaneously under such stress, the total electrical load would still be only about a tenth of what the common household hairdryer pulls. This observation reveals the important conclusion that only the smallest conductor size is needed for cables taking power to the subapertures, whether for a membrane or a rigid active segment. Currently, flight qualified twisted shielded pair cabling for this application masses around a kilogram for 750 meters.

Electrostatic charging systems have historically been massive because of large heat sinks associated with high voltage power supplies. This is a laboratory convenience though and need not translate to the space system. On the top of Figure 7 is a photograph of a very high voltage power supply built at MSFC and flown on the BATSE mission. Eventually, high voltage integrated circuits may become available even further reducing the electronics packaging mass.



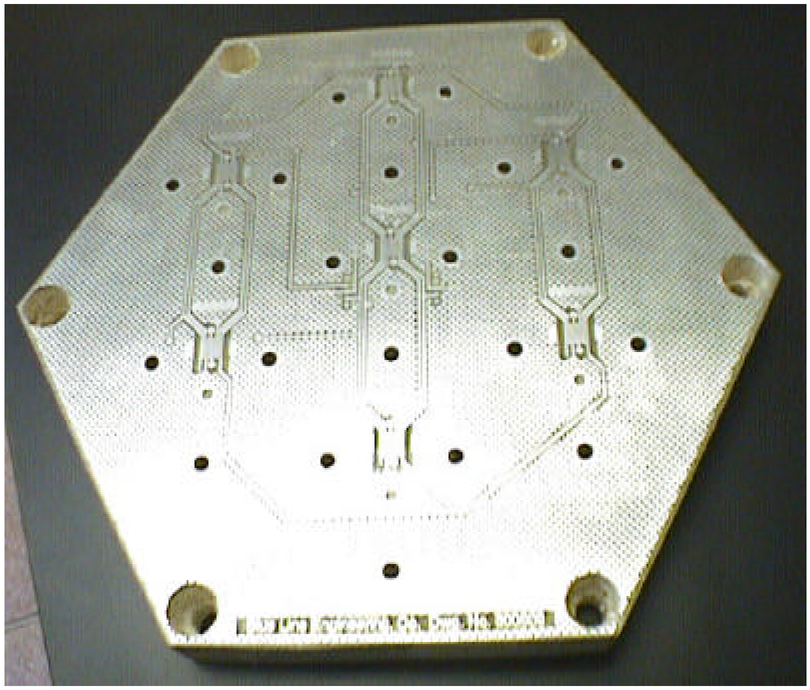


Figure 7 (Top) MSFC-built compact 5.5KV power supply for BATSE experiment, and (Bottom) Compact, integrated power and data services to an array of active mirror subapertures, [after Blue Line Engineering].

The photograph on the bottom of Figure 7 above shows control and signal conditioning electronics interconnects imprinted on the surface of a hexagonal supporting structure. It has been developed in conjunction with a seven segment active segmented array experiment designed and built by Blue Line Engineering. Distribution of these modest size components should not result in an overburdensome premium on powering and activating subapertures in large space telescopes. The only unresolved issue is the heat dissipation in cryogenic applications. A spreadsheet was constructed using component masses taken from these activities and the results are summarized in figure 8.

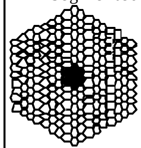
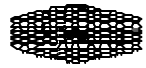
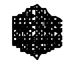
Mirror Option / Feature	Segmented Primary  210 segments 1.18 m diameter	Active Segmented Primary  210 segments 1.18 m diameter 630 sets actuator/sensor/electronics	Segmented Corrector  217 segments 16 cm diameter 637 sets actuator/sensor/electronics
Overall Diameter	20 meters	20 meters	2.7 meter
Segment Diameter	1.18 meters	1.18 meters	16 cm
Material	Zerodur on composite	Zerodur on Composite	Silicon Carbide
Actuation	mechanical	electromagnetic	electrostatic
Edge Sensors	no	yes	yes
Stroke (μm)	100	100	20
Power Required	none	segment 0.8 watts total 165 watts	segment 6.4 milliwatts total 1.3 watts
Mirror Weight Aux. Weight	segments 5900 kg aux. mass 6 kg total 5906 kg	segments 5900 kg aux. mass 20 kg total 5920 kg	segments 65 kg aux. mass 20 kg total 85 kg
Comments	Simple Construction Can Pack / Deploy	More Complex Const. Can Pack / Deploy	More Complex Const. Simple Packaging

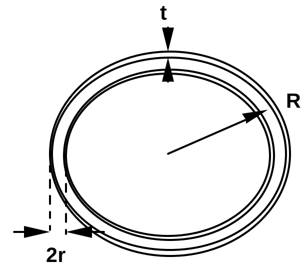
Figure 8. Characteristics of segmented mirrors

Considering the power consumption relationship as it applies to membrane mirrors quickly reveals that power system mass is even more modest than for rigid mirrors. This is because the power is a linear function of the mass being moved and for a twenty meter aperture the membrane is a couple of orders of magnitude lighter. In the case of electrostatically formed membrane mirrors, the power supply and cabling has reached a basic minimal value that must exist for a real system.

The estimating relationships for the membrane case are shown in figure 10 below. For the inflation case, a very thin cover shell was assumed over an aluminized reflector surface. The calculations show 20kg as the estimate for the reflector and 200 kg as estimate for the torus. In figure 9, the torus estimate is slightly increased to 280 kg to accommodate some fasteners between the membrane and the torus. To build the electrostatic case, it was assumed that the there would be four membranes with a conductor layer deposited on that has a mass similar to that of the aluminum layer on the fifth reflector layer. Because five separate toroids seemed unnecessarily pessimistic, it was assumed that a larger torus with greater dimension and slightly less than twice the mass of the inflation torus would be sufficient

Torus: Rubberized DuPont Kevlar fabric

r = 1.8 gm/cm^3
t = 1 mm thick
2r = 20 inch minor diameter
2R = 22 meters major diameter (10% over aperture size)

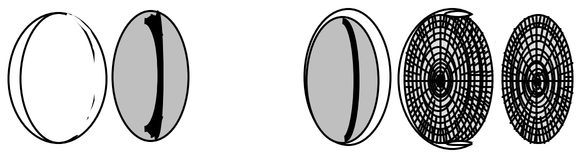


Torus: **W=[(2šr)t]2šR r = 4 š^{2}Rrt r**
= 4 š^2(1100 cm)(25cm)(0.1 cm)(1.8 gm/cm^3)
= 195, 418 gm
- 200 kg

Reflector: Aluminum coated Polyimide

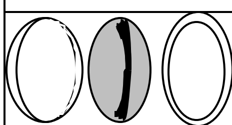
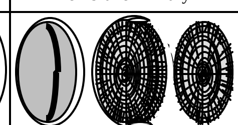
r$_{POLY}$ = 1.4 gm/cm^3 t$_{POLY}$ = 2.54 X 10 cm thick (-1 mil)
r$_{Al}$ = 1.4 gm/cm^3 t$_{Al}$ = 1 X 10^{-3}cm thick (-1000Å)
R = 11 meters major diameter (10% over aperture size to account for parabolic shape and torus attachment)

Reflector: **W= W$_{POLY}$ + W$_{Al}$ =(šR^{2}t$_{POLY}$) r$_{POLY}$ + (šR^{2}t$_{Al}$) r$_{Al}$**
= š(1100 cm)^2(1.4 gm/cm^3)[(0.0025 cm)+(0.001 cm)]
= 18, 839 gm
- 20 kg



(Major assumptions based on Inflatable Antenna Experiment (JPL/L'Garde))

Figure 10. Mass estimating relationships for membrane mirrors

		Thin Membrane	Active Thin Membrane Primary	Thin Membrane Corrector
				
Diameter		20 meters	20 meters	2.7 meter
Material		Polyimide	Polyimide	Polyimide
Shape Forming Mechanisms	hoop	toroid	2 toroids	toroid
	optic	pressure	electrostatic	electrostatic
Figure Error, μm rms		atomic scale: 25-90 Å mid-scale: **TBD** large scale: **TBD***	atomic scale: 25-90 Å mid-scale: **TBD** large scale: **TBD***	atomic scale: 25-90 Å mid-scale: **TBD** large scale: **TBD***
Adaptive Mechanism		none	electrostatic	electrostatic
Power Required		No	Yes	Yes
Mirror Weight & Aux. Weight		lens & mirror 20 kg torus 280 kg total 300 kg	plates & mirror 75 kg torus 550 kg power 25 kg total 650 kg	plates & mirror 3 kg torus 10 kg power 2 kg total 15 kg
Comments		Lens / gas attenuate photons Simple Construction Difficult Pack / Deploy	More Complex Const. Difficult Pack / Deploy	More Complex Const. Simple Packaging

* goal for IAE is 1-3 mm rms over 14m

Figure 9. Characteristics of Electrostatically and Gas Inflation Membrane Mirrors

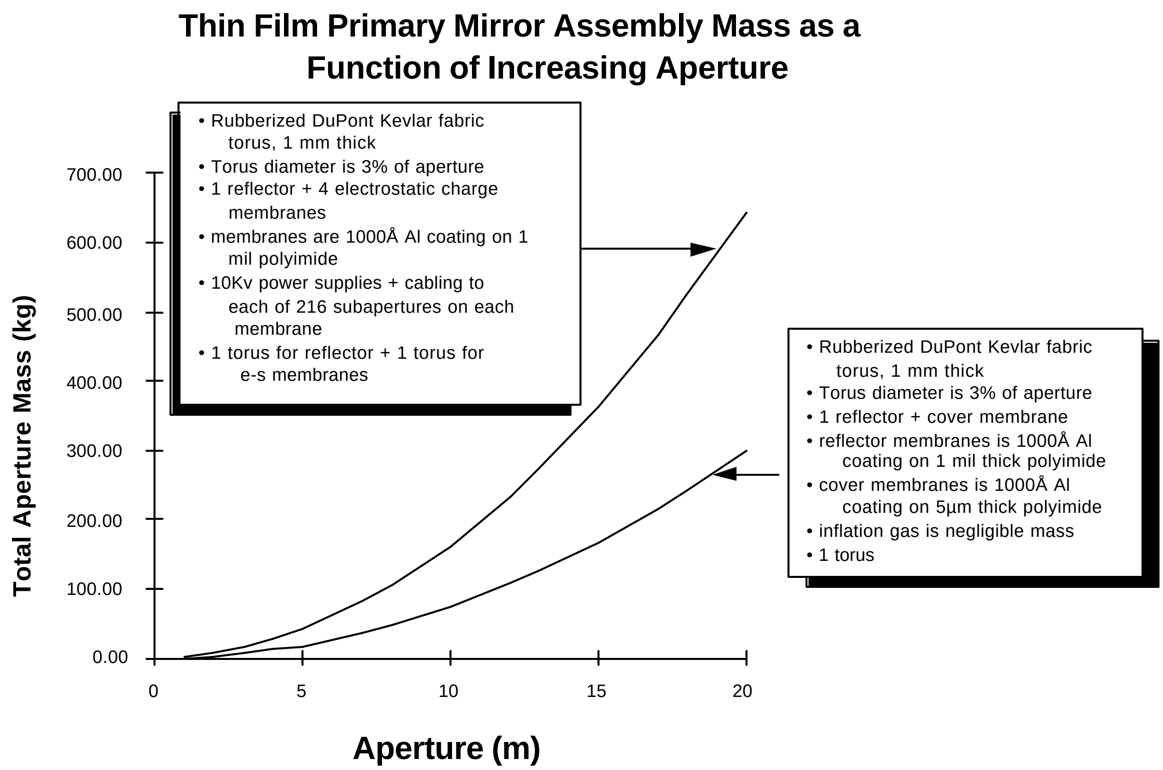
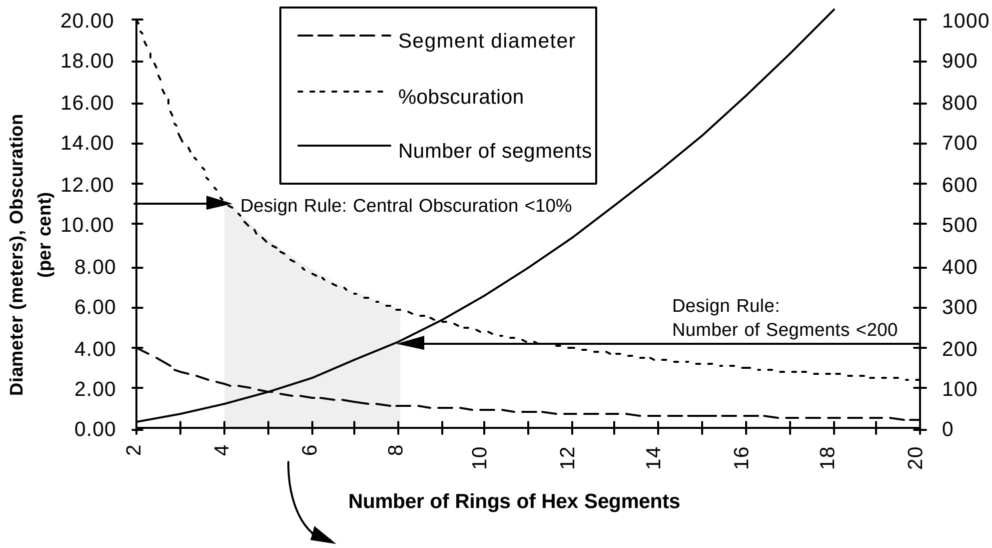


Figure 11. Thin Film Primary Mirror Assembly Mass versus Space Telescope Aperture

Other membrane alternatives include various materials on polyimides or treatments to the polyimides that make it possible to deposit control impulses as charge packets fired across space from an electron gun. This becomes difficult if gun and surface are separated more than a meter or if operated in intense regions of magnetic fields or those associated with sporadic solar events. For those design alternatives the total systems masses may vary from the assumptions here, but not significantly in comparison to the rigid mirror alternative.

<u>Sensitivities</u>

Several studies were available from these models useful in understanding the system design sensitivities. Figure 11 shows the not unexpected result that mass of membrane mirror options grows proportionately to aperture rather than diameter. It is interesting thought that this is not because of the growth of the aperture membrane mass, but instead it is dominated by the growth in the torus mass. This follows from an underlying assumption that the torus cross-section radius(r) will grow in constant proportionality to the primary mirror radius R such that R = 44r. The inflatable antenna experiment exhibits this property. The hundred-fold greater thickness of the torus material than the membrane material makes it always true that the torus is the greater mass component of the system. Discussions with SRS Technologies and United Applied Technologies, designers of large membrane solar collectors for solar thermal propulsion have validated the concept that the structure holding the membrane mirror and attaches it to the rest of the spacecraft dominate the total mass of the system.



Number of Rings	Segment dia. (cm)	% obscur	Number of segments
4	222	11.1	61
5	182	9.1	91
6	154	7.7	127
7	133	6.7	169
8	118	5.9	217

Figure 12 Full Aperture Mass versus number of segments for a 1-meter corrector mirror

Figure 12 shows the region of interest for estimating the mass of rigid segmented secondary mirrors. It informs that for 1-meter size mirrors and smaller the mass is dominated by terms that do not have any close correlation to the segment size. An example is the assumed 450grams of actuators, cabling, drive electronics, and other ancillary components. This is a fixed mass for each mirror segment, no matter what its dimension and mass. This plot shows the penalty for increasing segmentation. It follows that the secondary corrector should have no more than the least number of segments required to effectively compensate the spatial scale of wavefront errors.

The next plot (figure 13) shows the same data alongside calculations involving 10, 15, and 20-meter apertures. A very different conclusion is suggested by this result. When the larger apertures are not aggressively segmented, there is a mass penalty. This effect was described more fully in reference 3 as deriving from the mirror thickness and therefore mass being unnecessarily large. At some point in the increasing segmentation of the mirror, the increasing fixed masses mentioned earlier overwhelms the mirror mass penalty. This behavior is not evident in the one meter aperture and is weakly inherent in the 10 meter aperture. For larger apertures though, the mass penalties will be unacceptable unless the primary is divided into at least five and possibly up to 8 rings of segments. Further segmentation appears to achieve no more significant mass savings and would only be reasonable if the wavefront error spatial scale required such resolution in

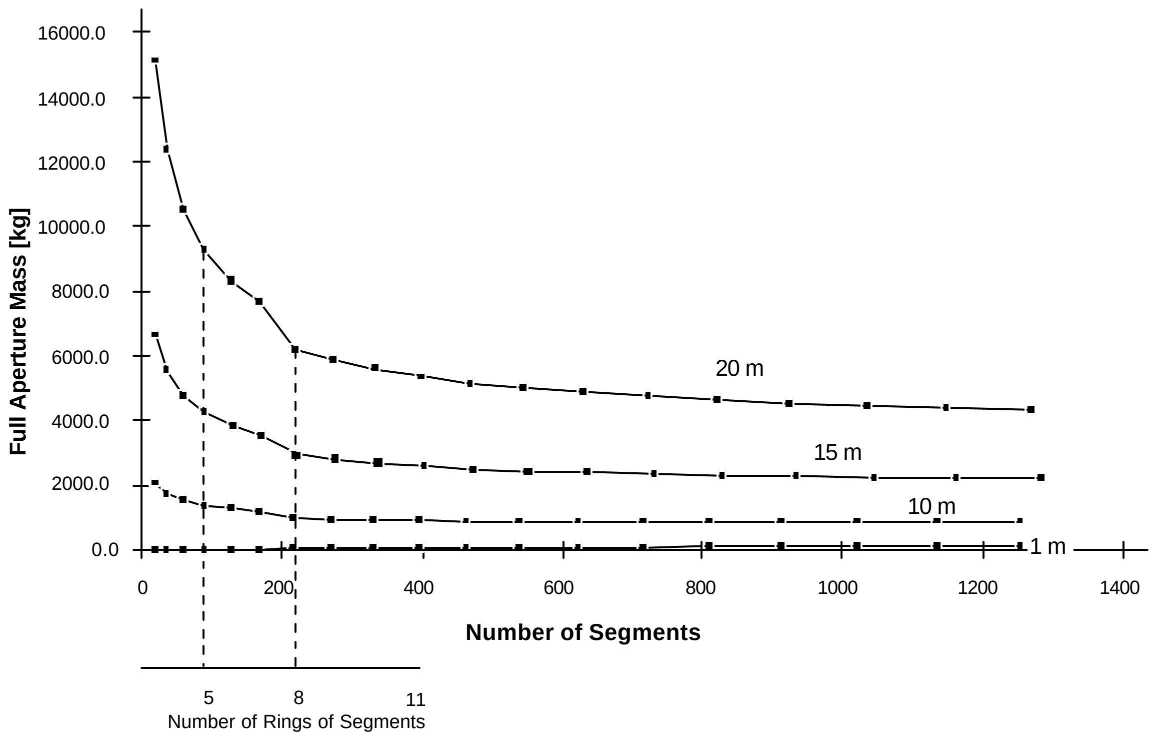


Figure 13. Sensitivity of total aperture mass for various size UV/IR space telescopes to degree of segmentation

the correcting system. From these results it can also be observed that even for stationary (not actively controlled) segmented primary mirrors, some degree of segmentation is appropriate to achieve mass savings. A simple rule that fewer segments are better is incorrect.

Conclusions

Figure 14 applies the full system (i.e. science instrument, spacecraft, and optical telescope assembly) mass modal for each of the permutations listed in figure 2 and 3 and plots the results side-by-side for comparison. In addition, notations are made on the System mass axis indicating the limit of the payload mass capability of current launcher options to make delivery to the Earth-Sun L2 destination. First of all, none of the concepts were lightweight enough to be launched by Delta or Atlas class expendable launch vehicles. The Titan IV/Shuttle class launch capability was sufficient for only the membrane primary mirror options which all weighed in at around 7 metric tons. The rigid segment options would weigh almost three times as much at around 20 metric tons. The current Magnum launch vehicle (see figure 15) under study at

MSFC would have the capability to launch either system easily. A recent ground up design study[6] done based on a more aggressive assumption of an ultralightweight primary mirror mass of 5 kg/m2 demonstrated the leverage primary mirror mass has on the total system. Instead of a 20 metric ton 20 meter aperture, that study identified a 5 metric ton 25 meter aperture.

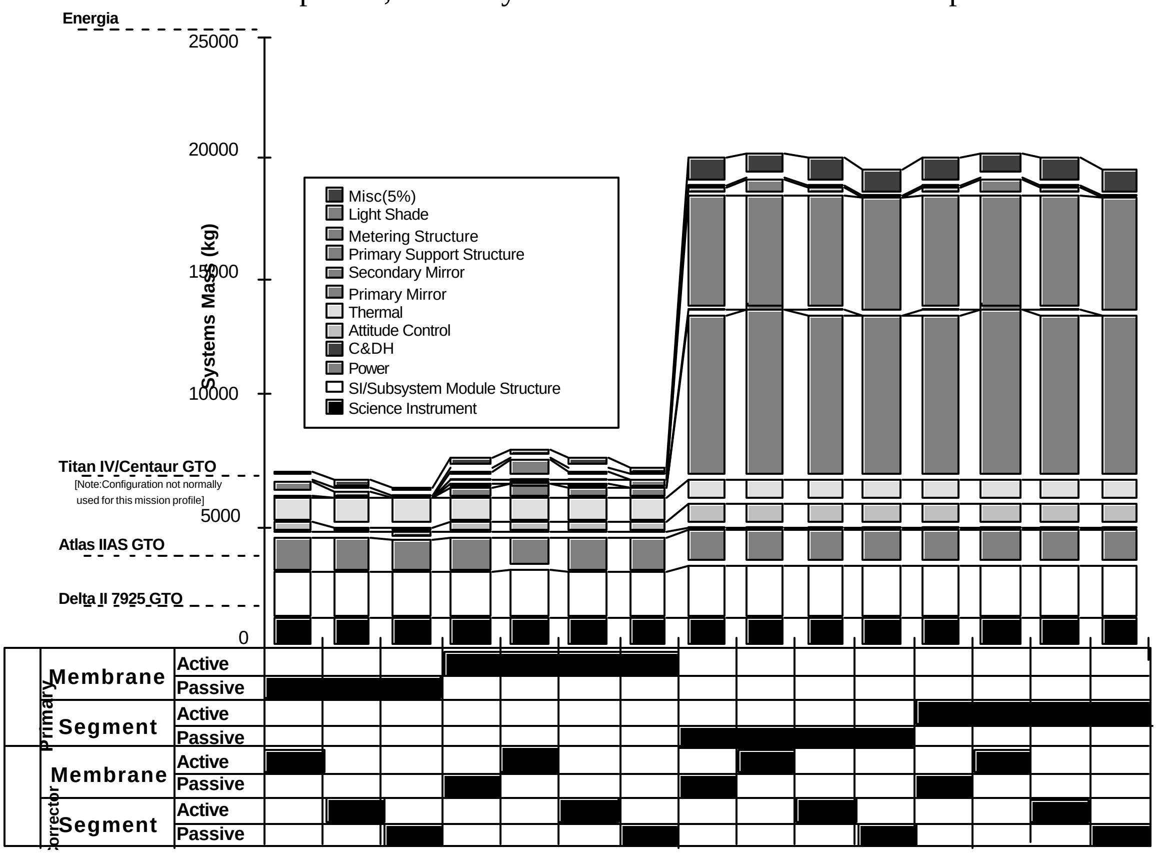


Figure 14. Comparison of Mass of 20-meter UV/IR space telescopes based on active or passively figured primary and secondary mirrors made of membranes or rigid mirror segments.

The various trade-offs between stationary versus active or correction on the primary versus on the secondary mirror had made no significant leverage on total system mass. This can be an extremely important design consideration if these options can all achieve the required optical performance.

Magnum Launch Vehicle withFlyback Boosters And LOX/LH2 Upper Stage

• Payload+upper stage to 31 X 220 nm transfer conic	90 metric tons
• Payload+upper stage after circularization at 220 nm	88 mt
• Payload+upper stage injection to L2	43 mt
• Upper stage propellant	47 mt
• Upper stage dry mass + adapter ($\Lambda = 0.8$)	12 mt
• Injected payload mass	31 mt

Figure 15. Ultra large launch vehicle possibility – the Magnum LV

As indicated in figure 15, the Magnum can launch a telescope payload as massive as 31 metric tons. This not the case however because volume limitations in the payload shroud come into play long before the payload mass capability of the transportation system. Assuming that ratios of deployed aperture to stowed payload diameter (80:1) and depth remain constant, a parametric plot is constructed in figure 16. It displays an estimate how large apertures might grow before they exceed the payload shroud limits of the Atlas IIARS, Shuttle, and Magnum launch vehicles. Two curves are shown to represent the membrane mirror case. It is assumed that efficiencies in packaging will be at least as good as those achieved in the 1997 Inflatable Antenna Experiment. The most optimistic end is anchored to a data point taken from the recent NGST design study for a deployed solar shield. The former case constrains significant structure and electronic hardware. The latter case has very minimal ancillary mass. The resulting curves show that even for the very light membrane mirrors weighing a single kg/m2 or less, the payload shroud volume will eventually limit the deployed aperture to something less than 100 meters.

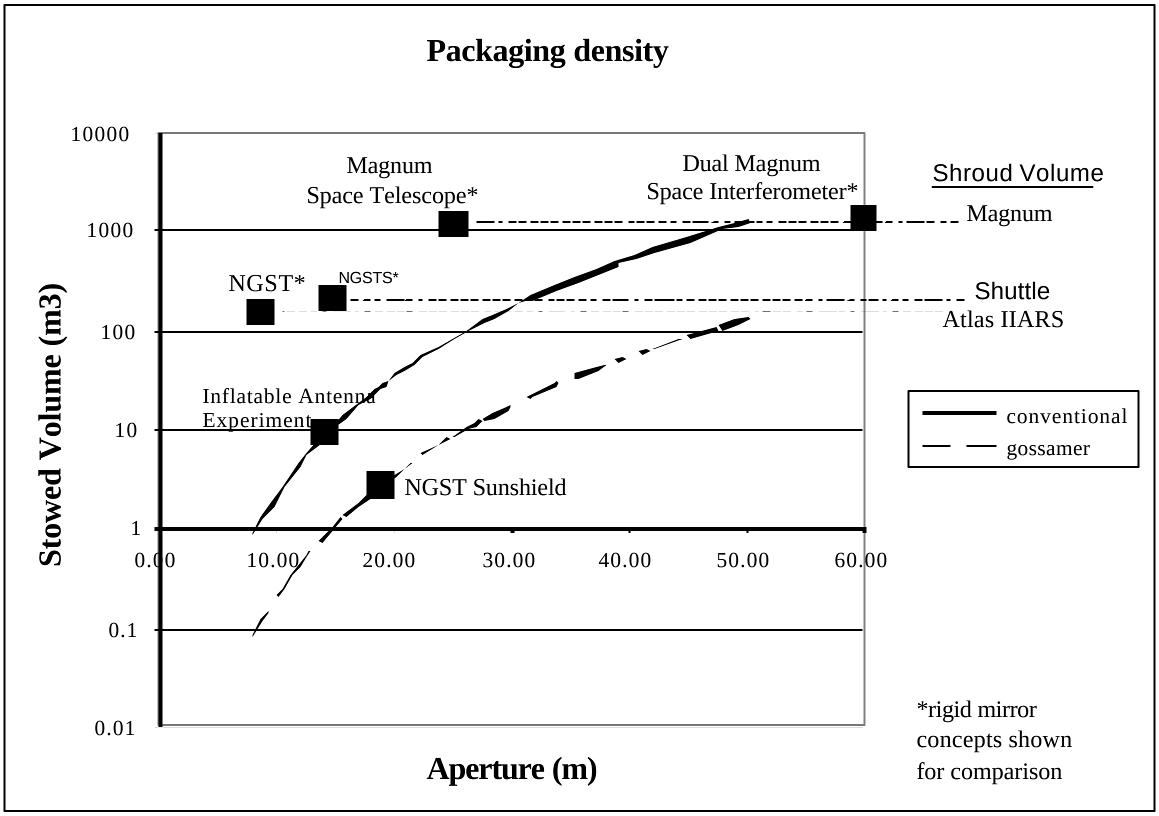


Figure 16. Launch vehicle payload shroud volume limits UV/IR space telescope aperture for either rigid or gossamer mirror technology

This being the case, the rigid mirror option continues to look promising. There might even be a potential to place two apertures connected together similar to the space interferometer (SIM) configurations or possibly something similar to the concepts under study for the SPECS mission. Such a system would provide tremendous optical capability in baseline resolution and sensitivity. If optical quality membrane mirrors are possible, then neither electrostatic nor inflation deployed systems have significant leverage over one another on total system masses. Another important observation about the membrane case is that for this technology, the primary mirror has finally given up its role as the major mass component of the system. The goal for those development programs will be to drive mass out of the science instrument and spacecraft subsystems like the attitude control system, EPS, TCS, and bus structure. But most importantly, **a major goal for the Gossamer program should be to be to achieve a very efficient packaging scheme that will make it possible to fill a launch vehicle to some significant fraction of its payload mass performance capability**.

The final conclusions are in light of the goals set out in figure 1. For a near or mid-term solution, technologies exist for 20+ meter apertures, but a magnum launcher is needed. In the far term, technology should allow placing a multiple, 20 meter aperture observatory to L2 economically in a single Magnum class (or more likely in that time frame) a program of reusable launch vehicle (RLV) operations.

References

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